

Comprehensive Marine Particle Analysis System

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LONG-TERM GOAL

The long term goal is development and utilization of a comprehensive (broadly capable) marine particle analysis system. The system is designed with wide dynamic range, thus, it will ultimately be used for high speed, high resolution characterization of water column particle fields in high, medium and low latitudes. As part of a broader goal this project continues advancement of the AOSN concept through development of both towed platforms and autonomous underwater vehicles.

OBJECTIVES

The project's objective is to develop a comprehensive marine particle analysis system, which, along with other sensor systems, will enable us to address basic oceanographic, environmental and ultimately military issues. The objective includes adapting and developing sensors to towed platforms and AUVs to characterize particle fields in a variety of oceanic environments.

APPROACH

The high resolution sampler (HRS) is designed to measure ocean properties that will provide insight into water column chemical, physical and biological processes. The platform has been used in Gulf of Mexico deployments to gather meaningful data and show efficacy. The approach for this project is to complete the sensor prototypes initiated in the period 1994 to 1999; test them at the USF Center for Ocean Technology (COT); sea-test them on the HRS towed platform; and then adapt sensors, as available, to AUVs. Deployments of the HRS in the Gulf of Mexico and deployments on AUV/ROVs

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are part of this project. Acquired data will allow researchers access to an enhanced data set for improvement and advancement of their models.

WORK COMPLETED

1. Shadowed Image Particle Profiling and Evaluation Recorder (SIPPER)

The SIPPER is being designed to be a tool that any researcher can use to repeatedly and easily collect high-quality images of plankton in seawater (figure 1). Building on the successful results of the prototype SIPPER instrument, major modifications are being made to the electronic subsystem to enable a three-fold improvement in resolution, simpler operation, and enhanced duration. The SIPPER redesign has been implemented in a sequence of stages, to enable optimization of individual subcomponents.

A pixel-by-pixel threshold algorithm was developed to eliminate artifacts caused by defects or debris on the optical windows, and has been further optimized to reduce the effects of spatial variation in the illuminating laser beams on the binarization threshold. The improved thresholding algorithms produce clear, noise-free images across the entire imaging window. A real-time data compression algorithm has been developed and successfully implemented on the field-programmable gate array (FPGA) hardware. Compression ratios of 30:1 have been typically observed during field use, varying slightly with particle load. The high compression allows us to store up to fifty hours of continuous images, from both cameras, onto a single disk drive before requiring offload. A pair of 23,000 line/second 4,096 pixel Dalsa line scan cameras have been purchased and been integrated into the existing optical system. We are in the process of integrating a paddle-wheel flow meter (0.1 to 6 meters/second range <1% error) into the sampled water stream; this will allow accurate volumetric measurements and image scaling in the along-flow direction. Full eight-bit gray scale data is transmitted from the cameras to the data storage system. Though yet to be implemented, the possibility exists to produce gray-scale images of the particles of interest.

A new higher-capacity PCI-based data storage system is being developed to allow Ethernet connectivity, a limited preview of stored images, and similar duration with the improved camera resolution. RF-Ethernet links are readily available on the market to allow wireless connectivity for AUV based applications of the instrument. All improvements listed are to be tested on an upcoming cruise in November 2001. Modifications to the COT flume are near completion; these will allow us to introduce calibration particles and cross-compare the results from SIPPER to the Dual Light Sheet and the *Focal Technology* Optical Plankton Counter.

Several of the improvements summarized above have required modifications of the control software. Each has been made to simplify operation. Additionally, user-friendly software has been written to automatically locate, extract, and size the particles from the collected images. These data and the particle's spatial information are recorded into a text file.

All of the hardware and software modifications above are being designed to work on a miniaturized version of the SIPPER instrument- the MIPPER. The layout of the optical system should be finished by the end of the year.

2. *Dual Light Sheet (DLS)*

The Dual Light Sheet (DLS) instrument is designed to allow real-time optical sizing and histogramming of particles in the HRS's 96 mm square sampling conduit. Laser light is used to illuminate a cross section of the sampling conduit. The light path is translated in the water flow direction using a pair of 45-degree angle mirrors. The light is then subsampled by a narrow aperture and collected onto a single photodiode. The resulting electrical current is digitized and sample by an embedded microcontroller. The signal is proportional to the attenuation caused by the particle's cross-section. Numerically integrating for the period that the particle flows past the aperture, the microcontroller determines the particles' area. The narrow aperture and numerical integration allows us to determine the area of particles much larger than the slit width, since we integrate the entire area of the particle as it passes the light beam (as opposed to sensors that take a single attenuation measurement caused by a particle obscuring a relatively wide beam). We also record precise timing information as particles obscure a portion of the illuminating light path. This allows each particle to be time stamped twice- once when encountering the primary beam path, and again when re-encountering the beam after the mirror reflections. A digital auto-correlation is performed on the digitally-sampled light signal, in theory allowing us to determine the average particle velocity within the sampling conduit.

The DLS was deployed on the HRS in February 2001. We successfully collected data from the instrument. Upon analyzing the data, a substantial problem was noted. We believe this problem will also plague other optical-attenuation based instruments (eg. the widely-used, commercially available OPC) that use a single element detector (imaging instruments are not prone to the problem), in productive coastal waters. The problem occurs when multiple particles are in the light field simultaneously (termed coincidence in the literature (Woodd-Walker et al., 2000)), and results in counting multiple smaller particles as a single larger one. The DLS, which uses a small aperture, effectively reduces the coincidence problem for the less-abundant large particles of interest. However, coincidence of small particles produces an indistinguishable train of pulses in the DLS, frustrating our ability to determine an accurate background light level. The problem is easily noted by viewing SIPPER images of the same water. There are such high numbers of small (<100 micron) particles in the water, that they nearly continuously distort the signal generated within the DLS (see figures 1D and 1L as examples). The remedy for the coincidence problem is to use a multi-element detector, which is precisely what an imaging system is. Since the SIPPER instrument can perform the same duties as the DLS, without coincidence problems, and additionally provide high quality images, we have concentrated our engineering resources on the development of SIPPER and MIPPER instruments.

3. *HRS Deployments*

HRS testing and sampling was conducted from February 17-23 at the HyCODE/ECOHAB: Florida site. Both SIPPER and the DLS operated continuously during this deployment. That data is currently being analyzed. New SIPPER with improved cameras, thresholding hardware and data storage, will be tested during a short cruise in October. A second HRS cruise will conduct sampling at the HyCODE/ECOHAB: Florida site from November 1-7 and complete the investigation of seasonal distribution of zooplankton grazers on the West Florida Shelf.

RESULTS

Wintertime conditions were sampled by the HRS in February 17-23 at the HyCODE/ECOHAB: Florida modeling site. Following our November cruise this year, a manuscript will be prepared investigating the seasonal dynamics of zooplankton distribution and grazing on the West Florida Shelf as a follow-up to our initial paper (Sutton et al., 2001). Multiple-season optical and biological data gathered during field sampling indicates that a tight biophysical coupling exists between the two components, emphasizing the need for synoptic multisensor sampling. Additionally, this data will be used to validate HyCODE / ECOHAB models.

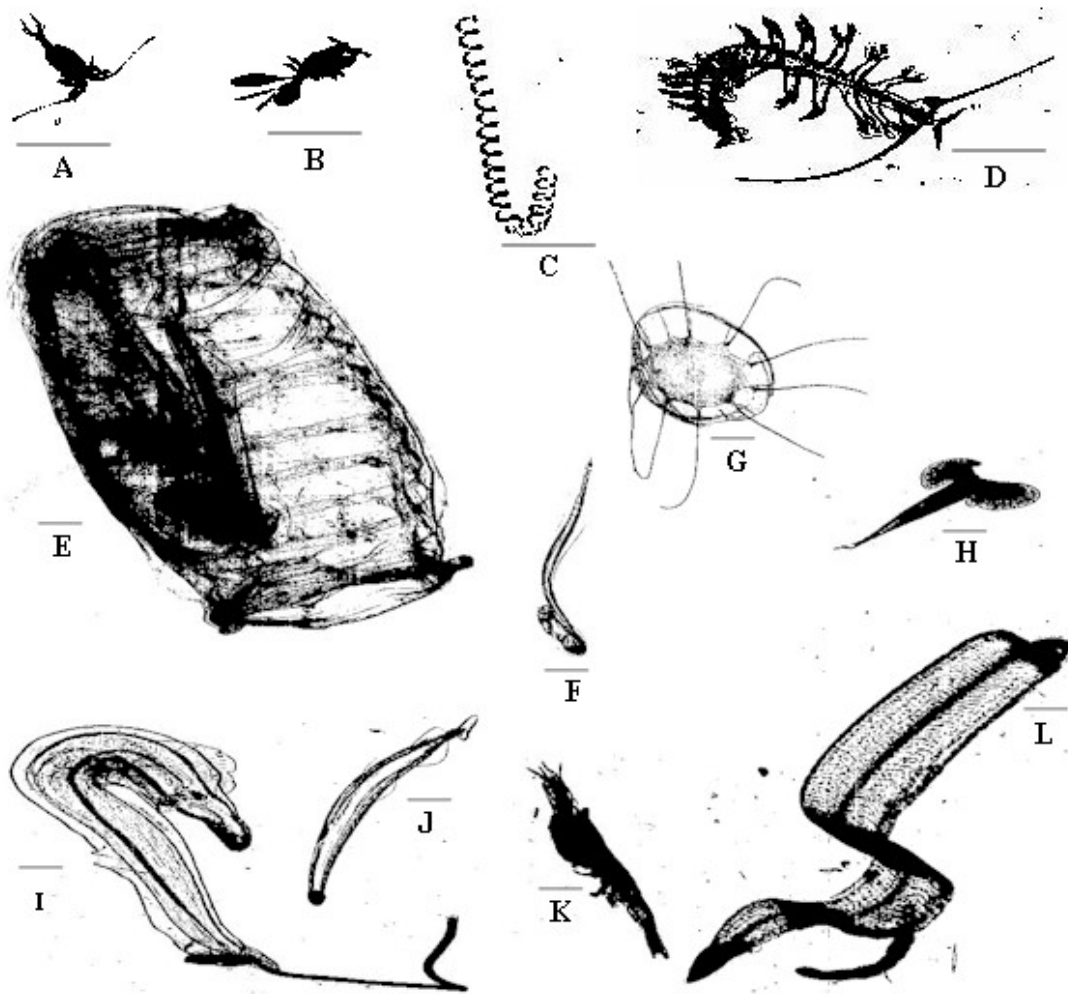


Figure 1. Examples of imaged zooplankton collected in the eastern Gulf of Mexico. Scale bars are equivalent to 2 mm. Images E-L are reduced by 50% to fit in the figure. A- Calanoid copepod, B- Poecilostomatoid copepod, C- Centric diatom chain, D- Polychaete, E- Salp, F- Larvacean, G- Hydromedusae, H- Pteropod, I- Heteropod, J- Chaetognath, K- Euphausiid, L- Leptocephalus fish larvae

Manual classification of SIPPER collected images (eg. figure 1) has been completed for a 10 net HRS deployment from July 24, 2000 in the eastern Gulf of Mexico. Over 40,000 organisms were imaged and classified from 10 discrete depth strata. A manuscript is in preparation comparing SIPPER data against concurrently collected Optical Plankton Counter and net data from this deployment. Initial results indicate that SIPPER determined concentrations of certain zooplankton taxa are many orders of magnitude higher than those calculated from concurrently sampling plankton nets, especially gelatinous and other fragile organisms that can be destroyed or pass through mesh during net collection (Table 1). This then has obvious implications for both optical and biological models that require accurate description of zooplankton and suspended particle populations.

Table 1. Comparison of normalized abundance of 14 net-collected and SIPPE-imaged zooplankton groups from a representative deployment at 10 m in the eastern Gulf of Mexico and calculated difference between the two sampling methods. The lower SIPPER values for copepods and pteropods probably result from the prototype SIPPERs difficulty in resolving small individuals of these groups with enough pixels for accurate identification.

	Net # m ⁻³	SIPPER # m ⁻³	% difference SIPPER/NET
Chaetognaths	16	40	+250
Copepods	1039	564	-54
Decapods	9	14	+156
Echinoderm	4	19	+475
Fish	0	0	*
Larvaceans	97	771	+795
Medusae	4	147	+3675
Molluscs	40	9	+444
Other crustaceans	5	17	+340
Polychaete	5	5	No difference
Protoctista	15	321	+2140
Salp and doliolids	31	102	+329
Siphonophores	17	24	+141
Trichodesmium	present in low numbers	1958	*

IMPACT/APPLICATIONS

This project represents a directed effort to build, test, and utilize systems for characterization of a wide variety of marine environments. Data gathered have direct application to predictive biological process models. The sensors being developed and tested are targeted for deployment on modern AUV's. Experience gained in deploying and developing sensors for AUV's will have significant impact on defining the appropriate tools for future automated monitoring of the ocean.

TRANSITIONS

The data output of this project will be of interest to programs such as HyCODE / ECOHAB. HRS data indicate that seawater optical properties at the HyCODE/ECOHAB: Florida site derive mainly from biotic activity (i.e. dissolved and particulate carbon) rather than sediment suspension processes. Others involved in the optical properties of water, and those creating biological - chemical - physical processes linked models will use the data. Data gathered will also be used in optimization of AUV sensor deployments. Ken Carder (USF) has expressed interest in utilizing SIPPER to investigate *Trichodesmium* vertical distribution and abundance in the Gulf of Mexico in an upcoming NSF proposal. *Trichodesmium* has recently been implicated in the initiation of harmful algal blooms along the Florida and Texas coasts (Lenes et al., 2001) and can now be resolved from spaceborne sensors (Carder et al., submitted). Therefore, accurate estimates of its abundance, vertical and size distributions are necessary to ground truth those instruments.

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